A Heterogeneous Agent Model of Energy Consumption and Energy Conservation

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[1]Czech National Bank, The views expressed herein are those of the authors and do not necessarily reflect the view of the Czech National Bank

Motivation

- In this paper we study *energy price shocks - monetary policy-energy conservation* nexus in a heterogeneous framework
- Both energy price shocks and monetary policy affect different groups of households differently
  - what are the main channels of distributional effects of monetary policy? Based on HFCS Slacalek et al. (2020): IES, somewhat smaller net interest rate exposure; large indirect effect through labour market
  - heterogeneity in energy consumption: share of raw energy expenditures in household consumption differs with the households' income Figure
- Investment into abatement capital reduces consumption exposure to energy price shocks; can have stimulative effect on economic growth
- Abatement and distributional aspects amplify (change) transmission of monetary policy in response to energy price shocks

Incremental contribution

- Q1: Does inflation targeting monetary policy influence households' energy conservation decisions?
  - it builds resilience to energy price fluctuations
  - it is beneficial to know if there is any monetary policy influence to be able to communicate these effects to the public and relevant public institutions
- Q2: What type of monetary policy response to energy price shocks is preferable?
  - the persistence and the "shape" of energy price shocks are important
  - we study how each type of policy affects agents' consumption energy intensity and welfare
  - there is a trade-off between stimulating employment and reducing inflation
  - is "looking-through" policy beneficial?
- We do not study: de-anchoring of inflation expectations, inflationary spirals, discretion versus commitment

Our results

- Monetary policy influences households' energy conservation decisions
  - through the labour market channel: by influencing the number of constrained agents and precautionary motives
  - by changing the return on nominal assets and credit interest
- When energy price shock hits, the policies with weaker response to inflation stimulate employment and result in larger energy capital holdings, but larger inflation and larger agents' welfare:
  - larger stock of energy capital reduces impact of energy price shocks on consumption volatility
  - better prospects of finding a job reduce future consumption volatility
- The policy of looking-through energy prices (reacting to core inflation) does not bring benefits in the medium term as it initially under-reacts, and over-reacts in the subsequent periods

Literature

- There is a growing literature on heterogeneous agents and distributional effects of monetary policy:
  - empirical work: e.g. Slacalek et al. (2020);
  - theoretical framework with endogenous labour market: Challe et al. (2017), Ravn and Sterk (2021);
- We relate to the literature on policy response to energy price shocks in HANK or TANK:
  - Auclert et al. (2023), Chan et al. (2022), Pieroni (2023):
  - we add abatement and energy conservation angle;
- We relate to the general equilibrium models of energy consumption and emissions:
  - Varga et al. (2022), Campiglio et al. (2022), Kiuila and Rutherford (2013)
  - they formulate abatement capital and costs in terms of reducing emissions

Model overview

- Search and matching frictions in the labour market, endogenous labour market tightness
  - vacancy costs, exogenous separation rate
- Households: employed, unemployed, firm owners (out of the labour-force)
  Equations
  - consume non-energy and energy goods (CES aggregator)
  - supply labour (inelastically) or earn firms
  - invest into abatement capital, nominal assets, physical capital (firm owners)
- Firms : Equations
  - use energy, labour and physical capital to produce non-energy goods
- Government: provides (unemployment benefits) and collect taxes
- Central bank (fully credible): conducts monetary policy in response to the deviation of inflation and/or output from the steady state

Key assumptions

- We employ assumption from Challe et al. (2017) of perfect risk-sharing among the *employed workers*.
  - households are grouped in identical families, a "planner" optimizes family wealth and redistributes (averages) nominal assets among the employed workers
  - guess-and-verify: first period unemployed do not "save their savings". The borrowing limits for unemployed workers is zero
- We set the borrowing limits for capitalists
- We adopt a similar assumption to holdings of abatement capital details
  - employed and unemployed workers live in separate "residencies" and move between the residencies when their employment status changes
  - workers can not take their abatement capital with them, which is taken by the state
  - guess-and-verify: unemployed workers do not invest into the abatement capital; steady state level is maintained from unemployment benefits
- As a result, we have four groups of households, but all the the channels we need
- The abatement capital is produced domestically

Simulations

- Parameters in the policy rule are constant!

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_r} \left[\left(\frac{E_t\Pi_t^p}{\bar{\Pi}}\right)^{\phi_\pi} \left(\frac{E_t y_t}{\bar{y}}\right)^{\phi_y}\right]^{1-\rho_r} \epsilon_t^r.$$

$$E_t\Pi_t^p = (E_t\Pi_t^c)^{1-\phi_e}(E_t\Pi_t^e)^{\phi_e}.$$

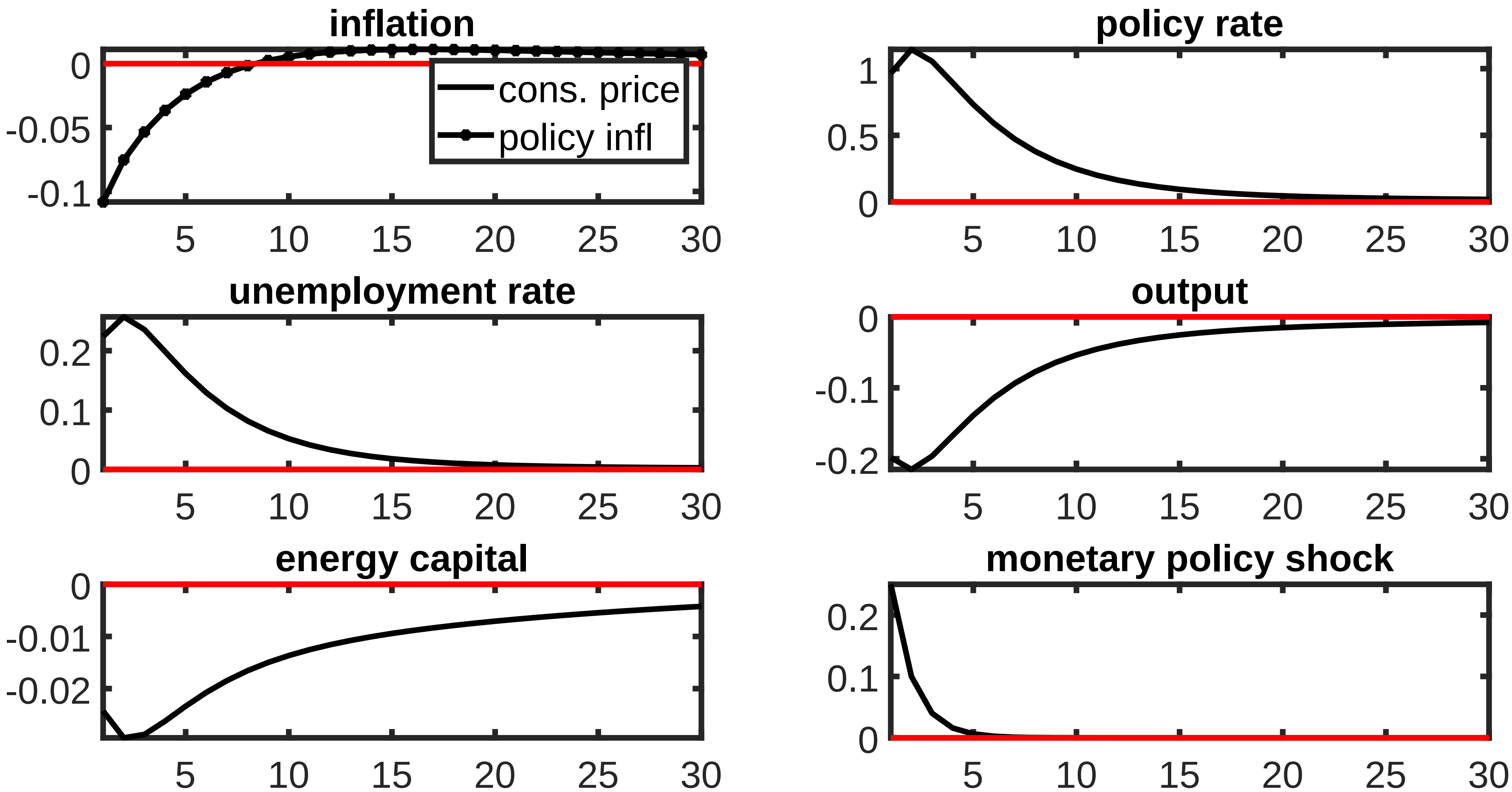
- Economy is initially in the steady state
- Model is linearised around the steady state
- Inflation expectations are perfectly anchored

Baseline policy rule: $\phi_y = 0$, $\phi_\pi = 2$. Calibration

- MP shock

- Energy price shock

Monetary policy shock: Baseline policy rule



Percentage deviations from the steady state; inflation and interest rates are annualized p.p. deviations ; unemployment is p.p. deviations.

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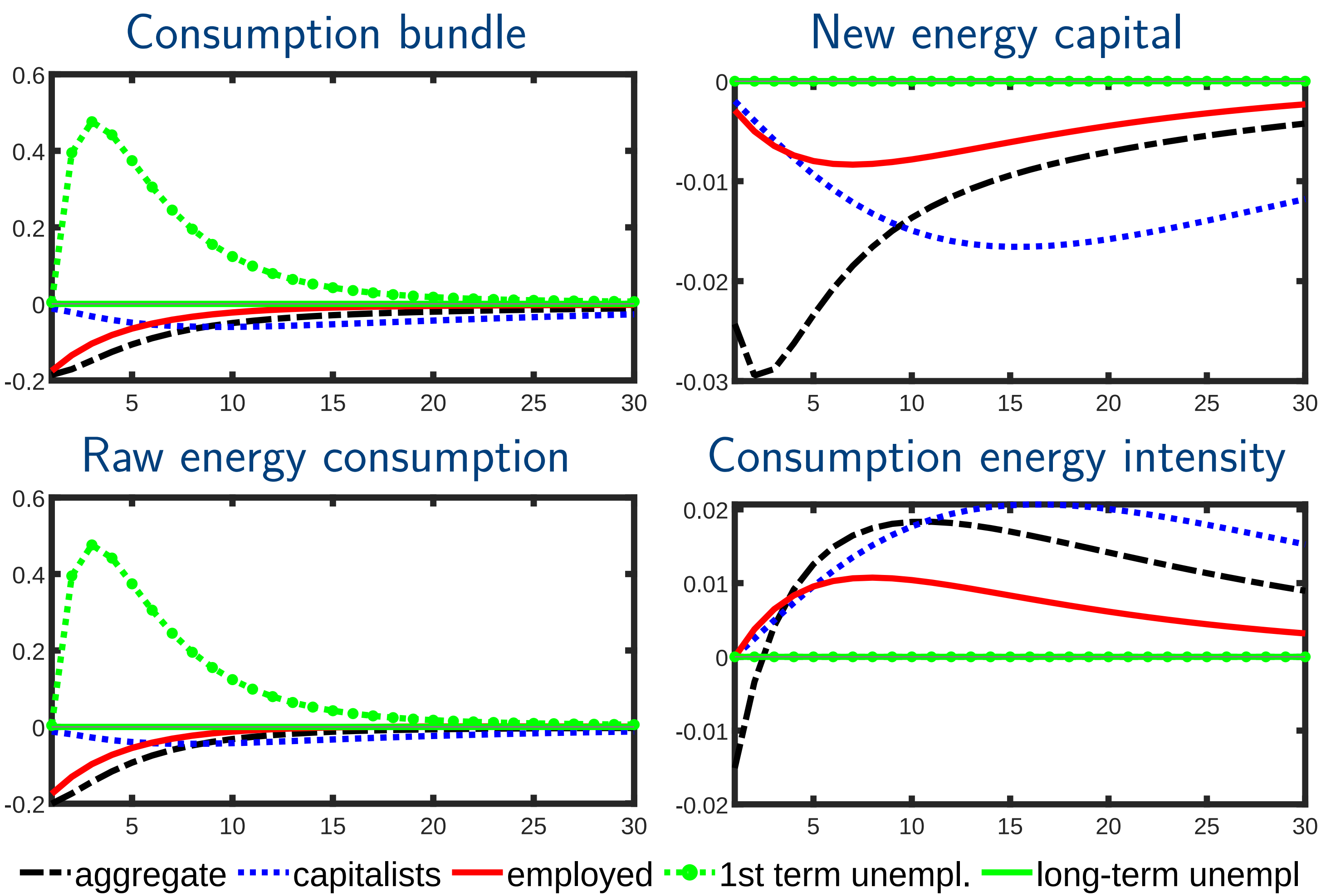
Monetary policy shock: Distributional effects



All responses are reported as percentage deviations from the steady state.

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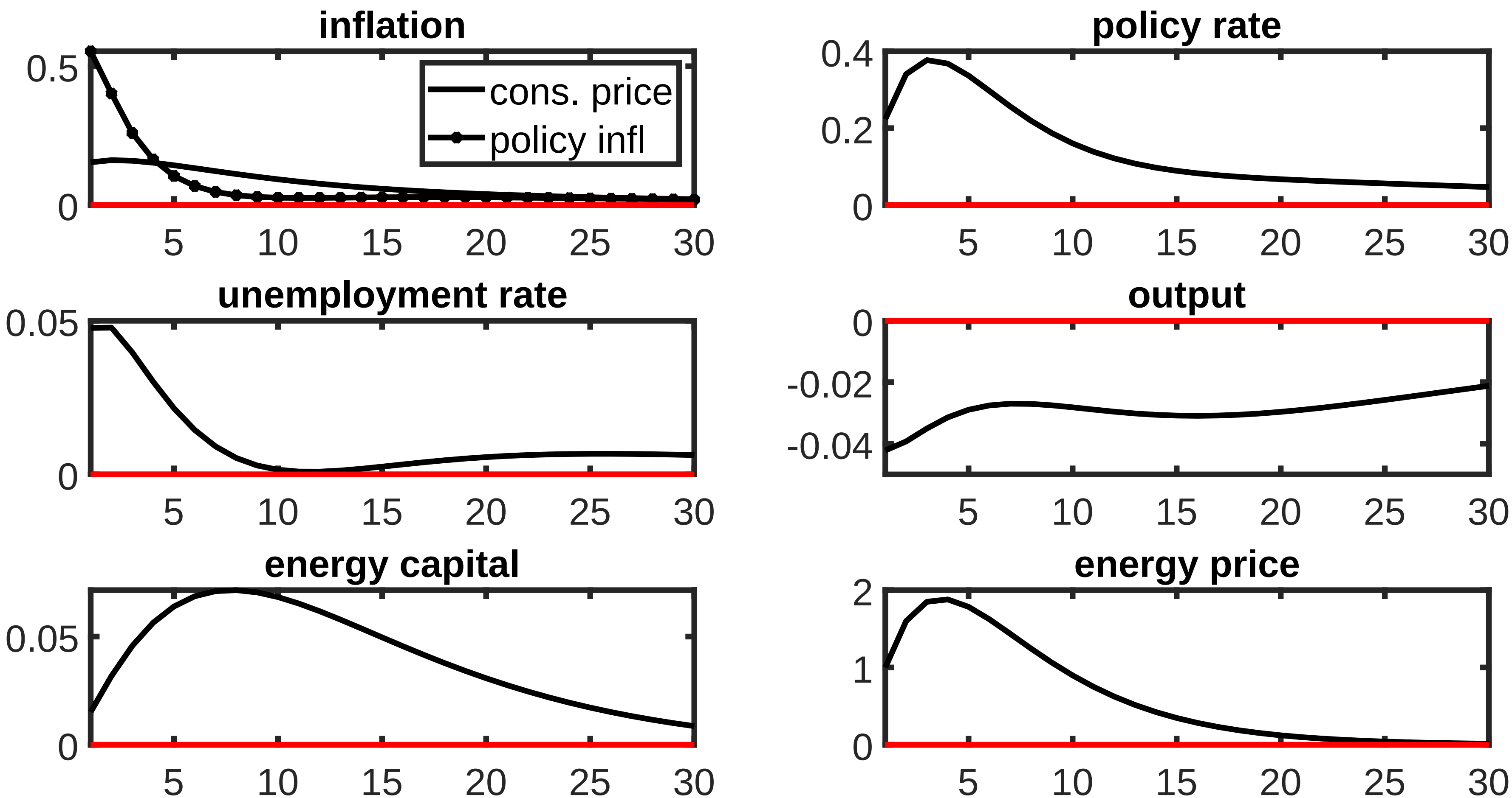
Energy price shock: baseline policy rule



Percentage deviations from the steady state; inflation and interest rates are annualized p.p. deviations; unemployment is p.p. deviations.

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Policy simulations overview

We vary the coefficients in the policy rule and the measure of inflation

	ϕ_π	ϕ_y	inflation measure
baseline	2	0	$E_t\Pi_t^p$
baseline+output	2	0.9	$E_t\Pi_t^p$
looking-through	2	0	$E_t\Pi_t^c$
optimal SR	1.1	2.31	$E_t\Pi_t^p$
optimal SR, looking-through	1.1	1.53	$E_t\Pi_t^c$

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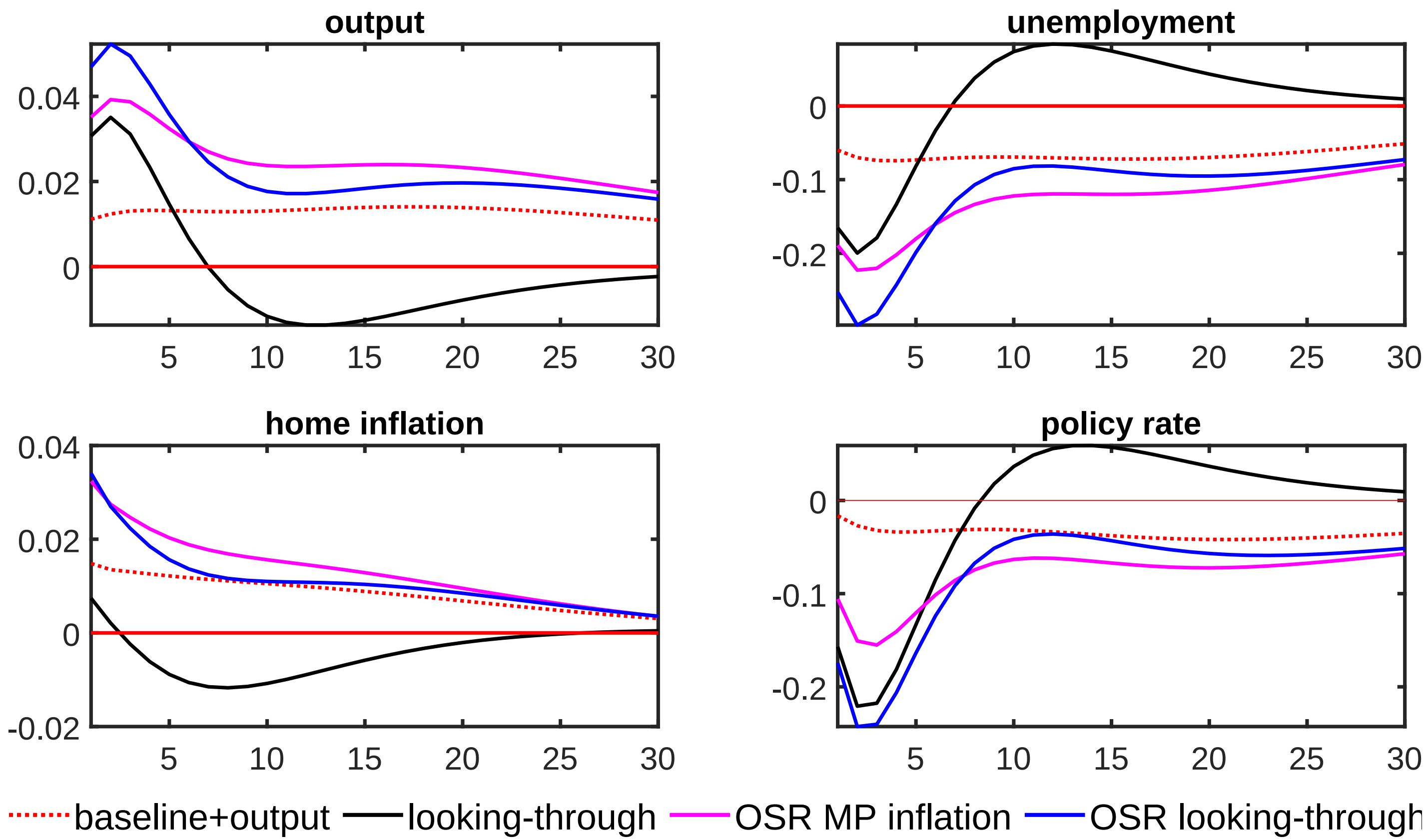

Percentage deviations from the steady state; inflation and interest rates are annualized p.p. deviations ; unemployment is p.p. deviations.

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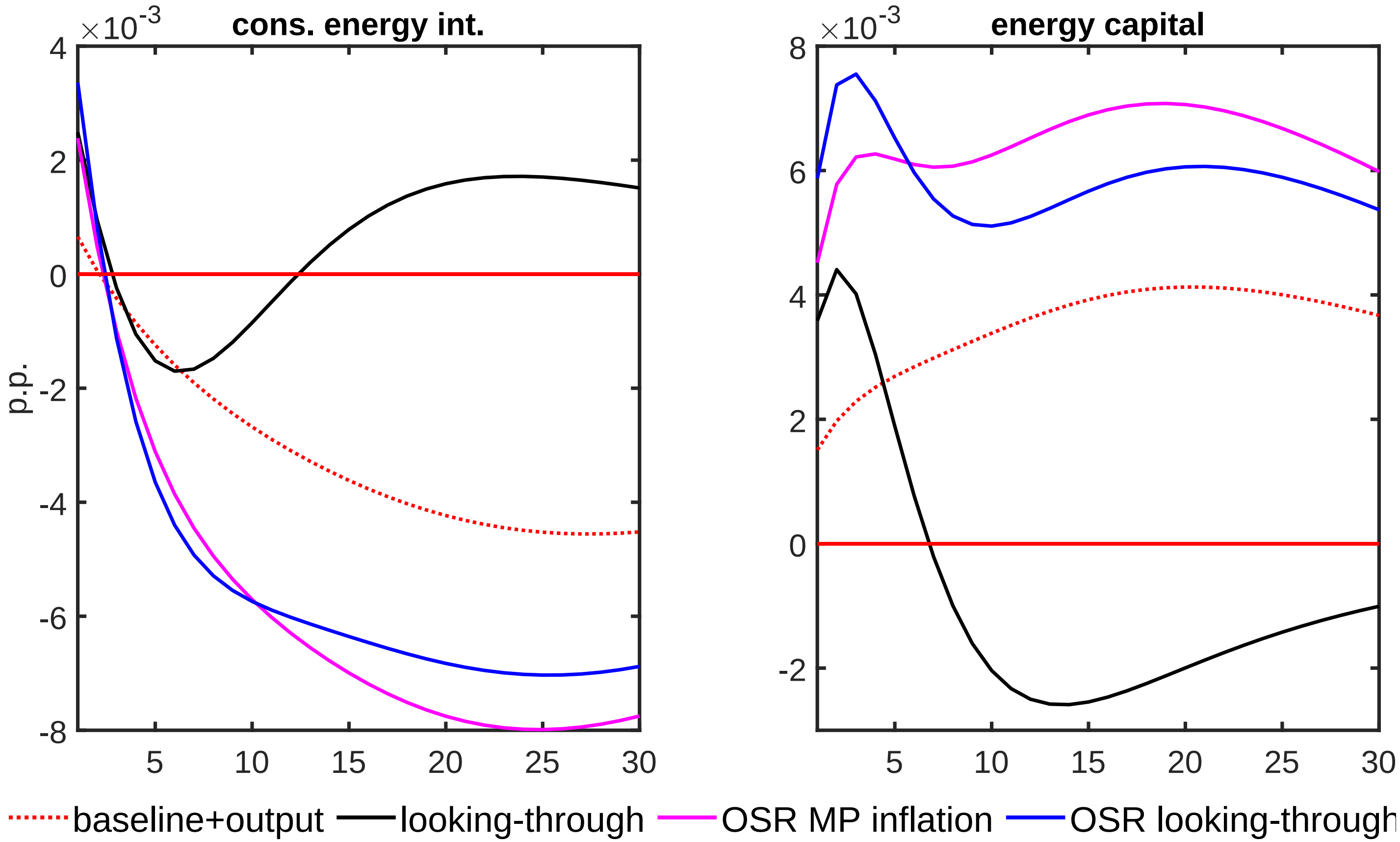
Policy simulations: Energy variables



Percentage deviations from the steady state.

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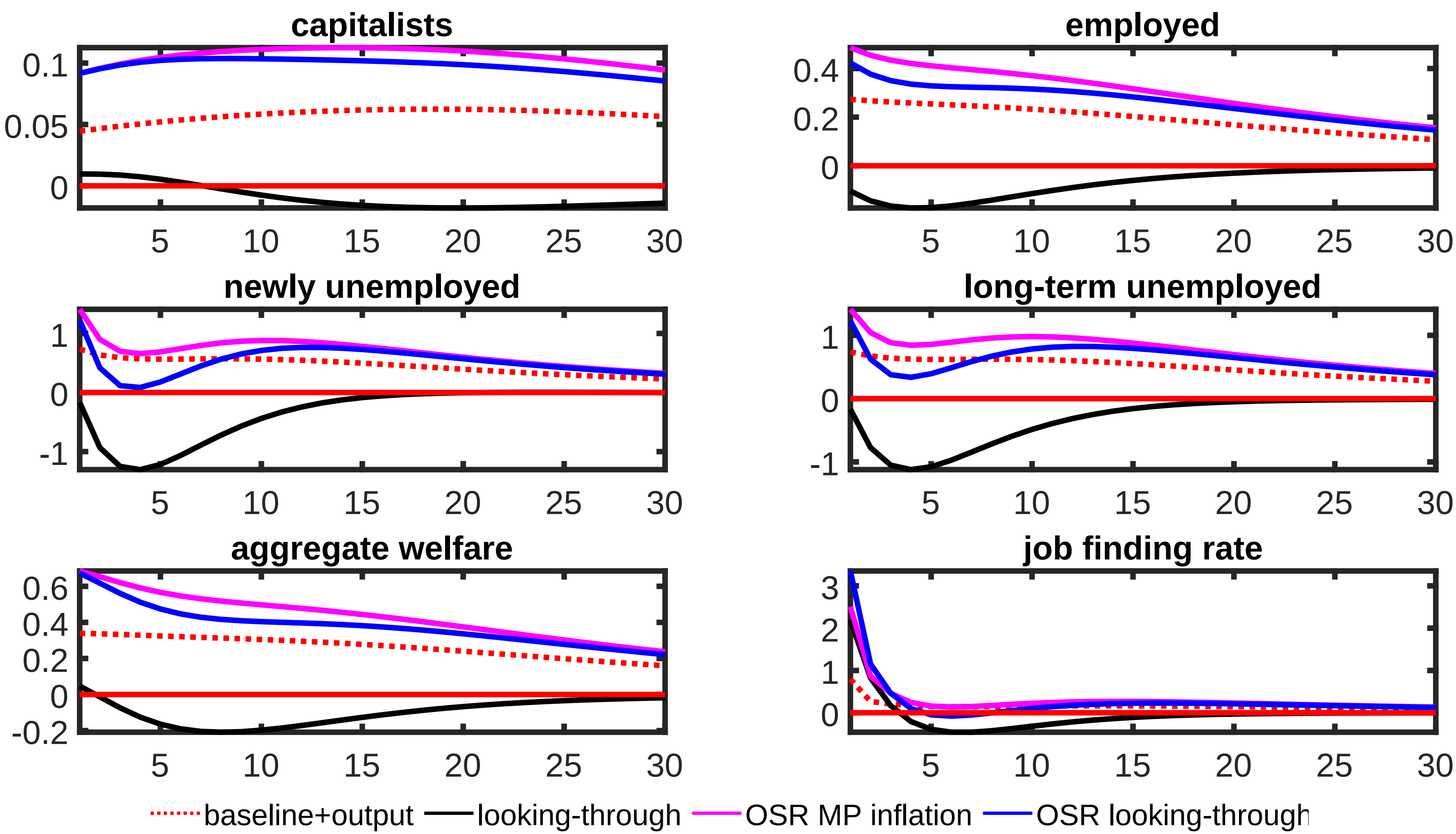
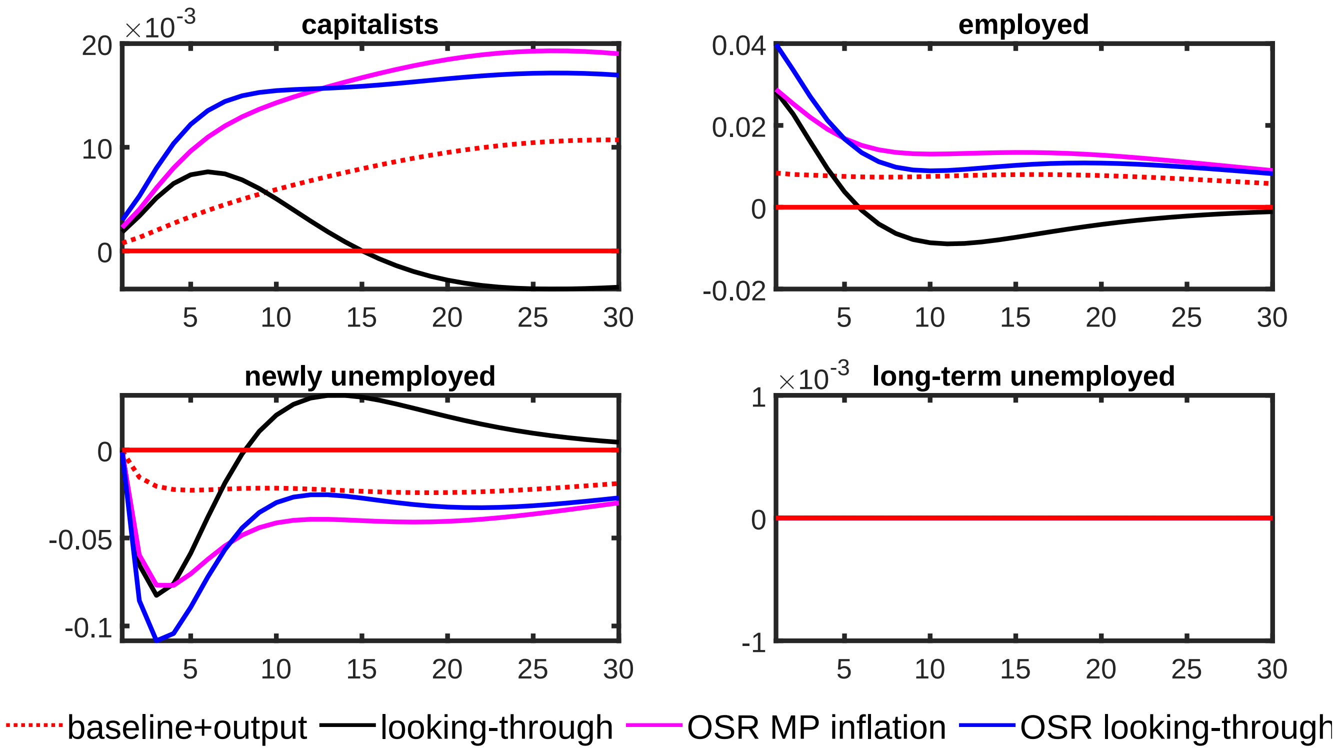
Welfare, 1% energy price shock



Percentage deviations from the steady state.

Consumption, 1% energy price shock



Percentage deviations from the steady state.

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Conclusions

- Monetary policy has an effect on consumption energy intensity through
  - asset returns and interest rate
  - labour market, by changing the number of HtM and precautionary motives
- Too restrictive monetary policy in response to the energy price shock dampens investment into abatement capital, which
  - insulate the economy against the energy prices fluctuations
  - can stimulate domestic production
- The agents' welfare is larger when consumption is more resilient to energy price shocks, and there are more job opportunities

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Rigid nominal benefits: Overview

We vary the coefficients in the policy rule and the measure of inflation

	ϕ_π	ϕ_y	inflation measure
baseline	2	0	$E_t\Pi_t^p$
baseline+output	2	0.9	$E_t\Pi_t^p$
looking-through	2	0	$E_t\Pi_t^c$
optimal SR	1.1	5	$E_t\Pi_t^p$
optimal SR	1.1	5	$E_t\Pi_t^c$

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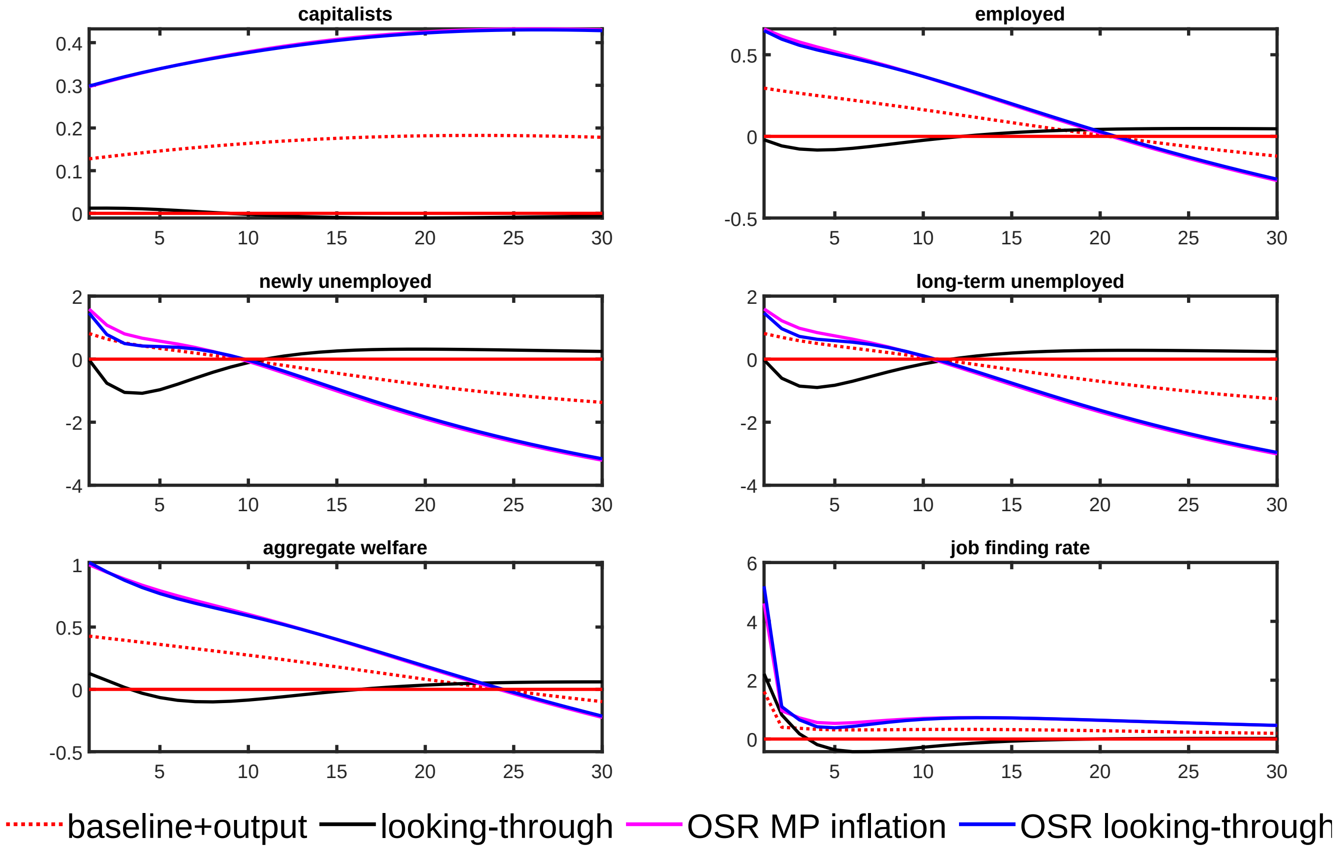
Welfare: Rigid benefits



Percentage deviations from the steady state

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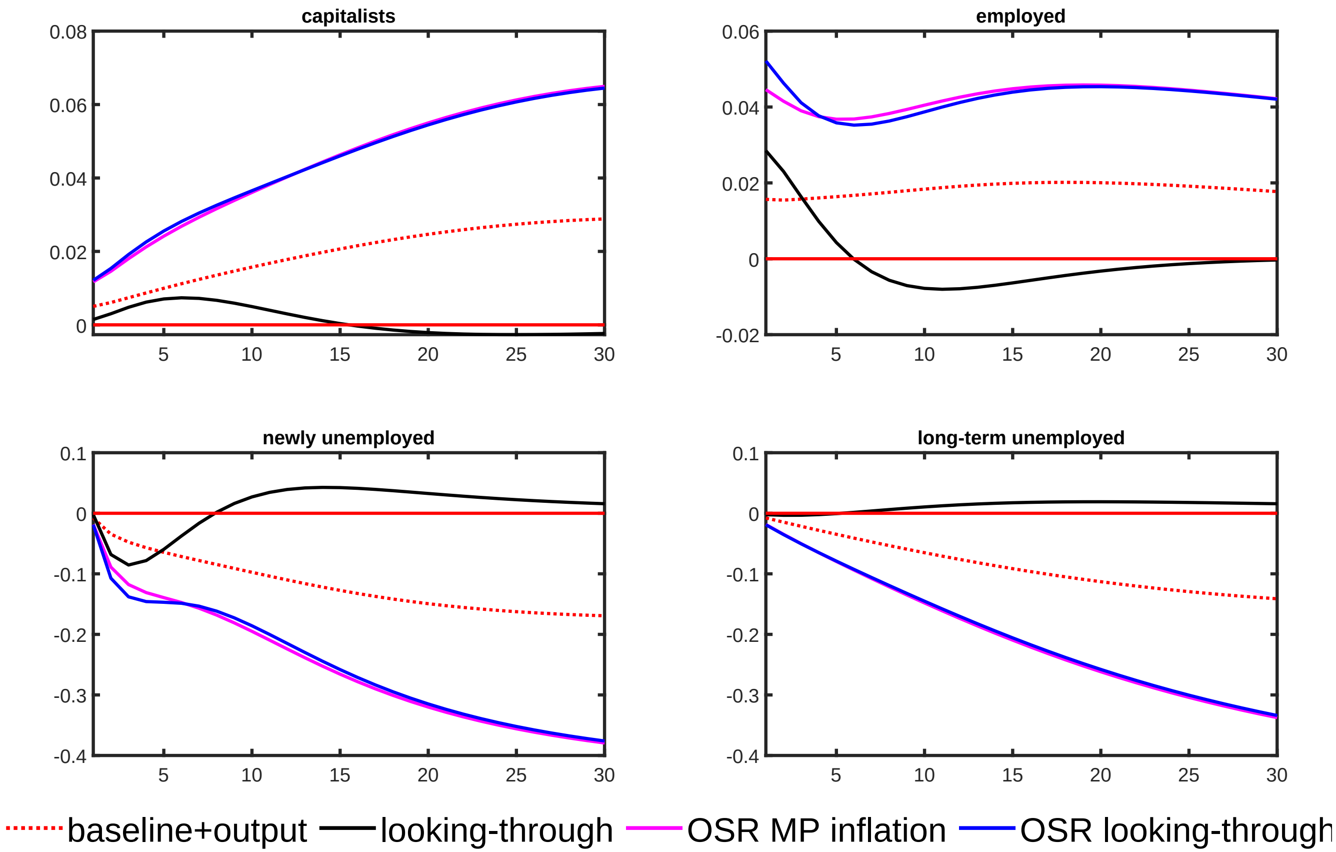
Consumption: Rigid benefits



Percentage deviations from the steady state

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Share of energy expenditures, income quantiles

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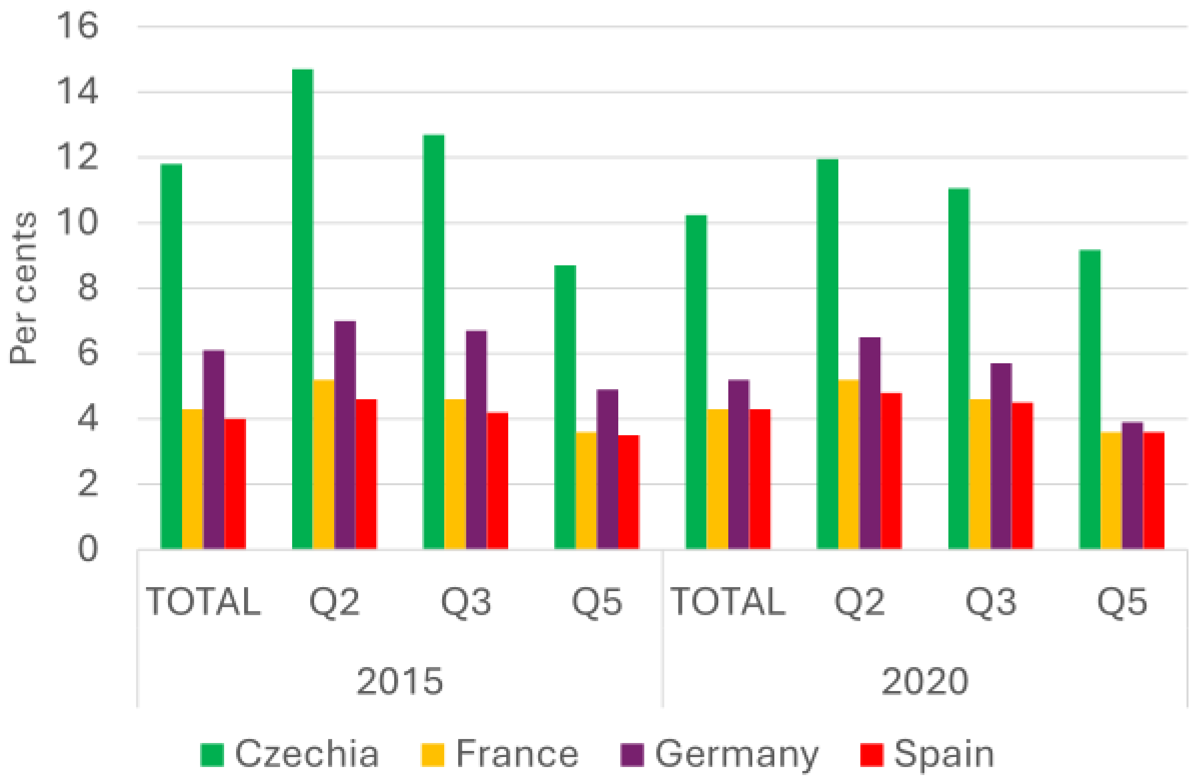
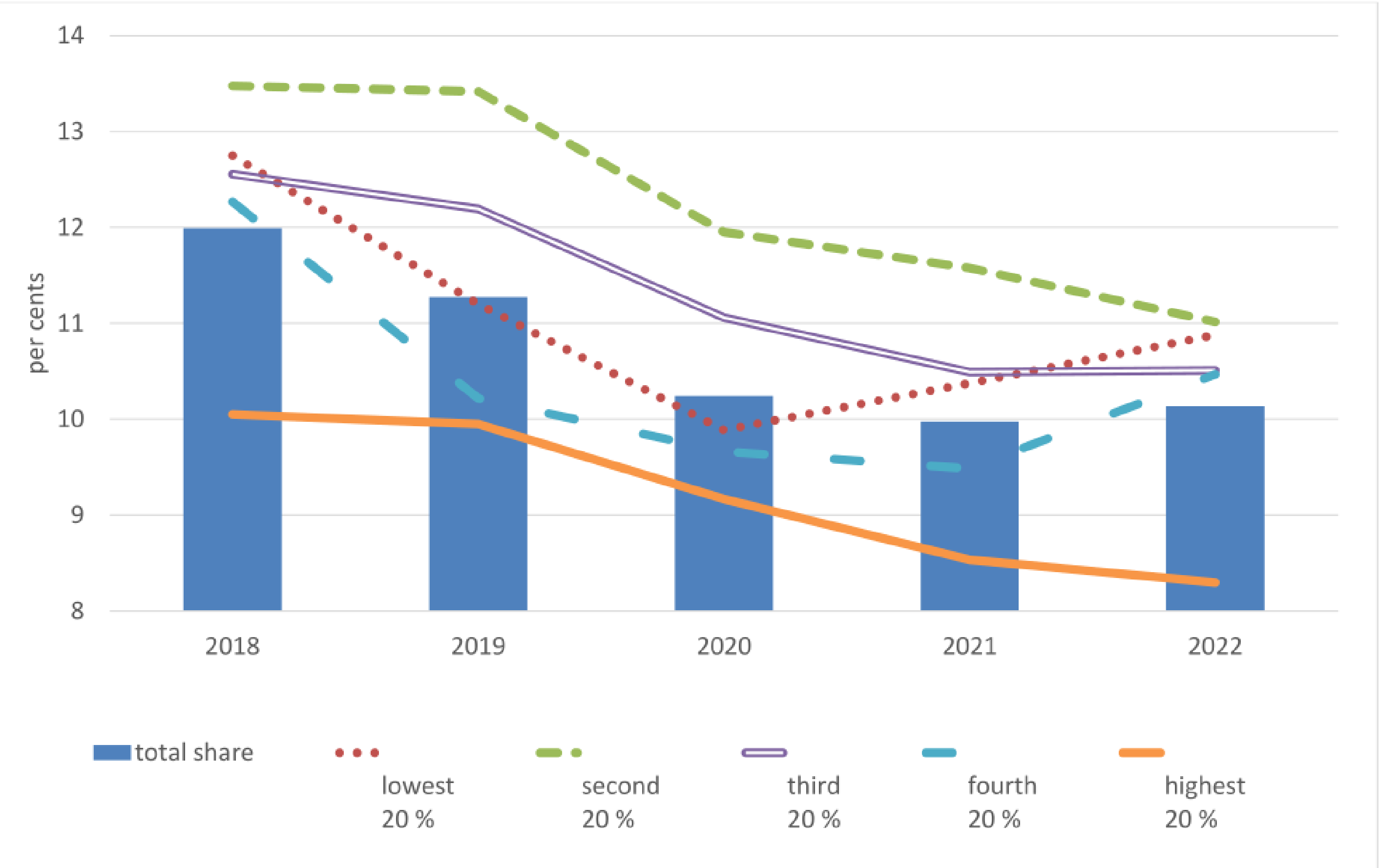


Source: Eurostat based on national budget surveys

Motivation

Share of Energy Expenditures: Income Quantiles



Source: National budget survey

Motivation

Household's problem

Each household maximizes the following utility subject to their expected employment status.

$$U_t(h) \equiv E_t \sum_{j=0}^{\infty} \beta^j \frac{\mathbb{C}_{t+j}(h)^{1-\mu}}{1-\mu}, \tag{1}$$

μ - relative risk aversion; $\mathbb{C}$ - composite consumption good; E^s - energy services; C - non-energy consumption good. The composite consumption good is:

$$\begin{aligned}
\mathbb{C}_t(h) &= \left[(1-\phi_e)^{\frac{1}{\lambda_e}} C_t(h)^{\frac{\lambda_e-1}{\lambda_e}} + \phi_e^{\frac{1}{\lambda_e}} E_t^s(h)^{\frac{\lambda_e-1}{\lambda_e}}\right]^{\frac{\lambda_e}{\lambda_e-1}}, && (2)\\
E_t^s(h) &= f(K_{h,t-1}^e) E^r(h)_t = \psi (K_{h,t-1}^e)^2 E^r(h)_t, && (3)\\
E^r(h)_t &= \frac{1}{\psi} (K_{h,t-1}^e)^{-2} E^s(h)_t, && (4)\\
K_t &= (1-\delta_e) K_{t-1} + I_t^e. && (5)
\end{aligned}$$

Model

Households: employed, unemployed, firm owners (out of the labour-fource)

Budget constraint:

- revenue side: for employed household nominal wage $(1-\tau)W_t$, for unemployed nominal benefits $P_t W_{\mu,t}$, for a firm owner - dividends and return on capital $(1-\tau)Rev$; return on bonds B_{t-1};
- expenditure side: consumption of goods and raw energy, C_t and E_t^r; nominal bond holdings B_t, investment into capital I_t and into abatement capital I_t^e, $P_t^I = P_t$ is price of a domestically produced good. The agents pay portfolio and investment adjustment costs Ψ_b and Ψ_k.

Denoting after tax household income $\tilde{W}$:

$$P_t C_t + P_t^e E_t^r + B_t + \Psi_b(B_t, \bar{B}) + P_t I_t + \Psi_k(I_t, I_{t-1}) + P_t I_t^e + \Psi_k(I_t^e, I_{t-1}^e) \\ \leq \tilde{W}_t + R_{t-1} B_{t-1}, \quad (6)$$

Model

Monopolistic competition, Rotemberg pricing tradition, production function:

$$Y_t = min\left[\frac{1}{1-\rho_o}A_t N_t^{1-\gamma_k} K_{t-1}^{\gamma_k}, \frac{1}{\rho_o}E_t^{rp}\right] \tag{7}$$

Competitive final good producer, first-order conditions:

$$Y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\gamma} Y_t, \tag{8}$$

Firms pay post $v_t \geq 0$ vacancies and pay $\kappa > 0$ for each vacancy.
Labour market matching function is Cobb-Douglas:

$$m_t = e_t^{\alpha} v_t^{1-\alpha}, \tag{9}$$

Challe et al. (2017), Hall (2005): rigidity in nominal wages. In real terms, the process for real wages is modelled as in Challe et al. (2017):

$$W_t = \left(\frac{W_{t-1}}{\Pi_t}\right)^{\gamma_w} \left(\bar{W}\left[\frac{\eta_t}{\bar{\eta}}\right]^{\chi}\right)^{1-\gamma_w}, \tag{10}$$

Model

Nominal assets are average among employed workers:

$$\tilde{b}_{e,t} = \frac{1}{e_t} \left[(1 - \omega (1 - \eta_t)) \, e_{t-1} b_{e,t-1} + \eta_t u_{t-1} \cdot 0 \right]. \tag{11}$$

The abatement capital is the same within the workers' employment status :

$$\tilde{k}^e_{u,t} = \bar{k}^e_u, \tag{12}$$

$$\tilde{k}^e_{e,t} = k^e_{e,t-1}. \tag{13}$$

Back

Households' types

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Agent	Income	Nominal Assets	Abatement Other Assets
employed, unconst.	wages	savings	K^e
poor HtM: 1st per unemp.	3/4 benefits	savings, t-1	low K^e
poor HtM: long-period unemp.	benefits	no	low K^e
rich HtM: capitalists	firms dividends	debt	K^e, K, firms

Back

- employed workers:

$$P_tC_t + P_t^eE_t^r + B_t + \Psi_b(B_t, \bar{B}) + P_t^I I_t^e + \Psi_k(I_t^e, I_{t-1}^e) \leq (1-\tau)W_t + R_tB_{t-1},$$
$$I_t^e = k_{e,t}^e - (1-\delta_e)\tilde{k}_{e,t}^e;$$

- poor HtM: first period unemployed

$$P_tC_t + P_t^eE_t^r + P_t^I I_t^e \leq P_t 0.75 W_{\mu,t} + R_tB_{t-1},$$

or unemployed for longer than 1 period

$$P_tC_t + P_t^eE_t^r + P_t^I I_t^e \leq P_t W_{\mu,t},$$

both types: $I_t^e = \delta_e \tilde{k}_{u,t}^e$;

- rich HtM: firm owners

$$P_tC_t + P_t^eE_t^r + B_t^c + P_t^I I_t^e + P_t^I I_t + \Psi_k(I_t, I_{t-1}) + \Psi_k(I_t^e, I_{t-1}^e) \leq (1-\tau)Rev_t$$
$$I_t^e = k_{c,t}^e - (1-\delta_e)k_{c,t-1}^e, \quad I_t = k_t - (1-\delta_e)k_{t-1},$$
$$B_t^c = \frac{\sum_{\text{empl.w.}} \bar{B}}{\text{number of firm owners}}, \quad \beta_t^c = \beta\left(k_{t-1}/\bar{k}\right)^{-\psi_k\beta}.$$

Back

Calibrated parameters

Name	Symbol	Value
Energy consumption:		
Share of energy in CES aggregator	ϕ_e	0.1
Elasticity of substitution	λ_e	0.3
Energy capital depreciation	δ_e	0.01
Energy share in output	ρ_o	0.05
Labour market:		
Steady state job finding rate	$\bar{\eta}$	0.15
Share of firm owners	ξ	0.12
Adjustment costs:		
Portfolio adjustment costs'	ψ_b	0.03
Capitalists' discount factor adjustment	ψ_k	0.1
Abatement capital adjustment costs	ψ	0.005
Abatement and preferences:		
Abatement parameter	$1/\psi_{ab}$	1/29
Discount rate	β	0.95

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Name	Symbol	Value	
		Model	Data
Workers' savings to wealth ratio	$\bar{B}_t / \overline{Net\ wealth}$	0.077	0.068
Share of workers energy expenditures	$\bar{E}^r_n / (\bar{E}^r_n + \bar{C}_n)$	0.10	0.11
Share of poor HtM energy expenditures	$\bar{E}^r_e / (\bar{E}^r_e + \bar{C}_e)$	0.12	0.12
Share of capitalists' energy expenditures	$\bar{E}^r_c / (\bar{E}^r_c + \bar{C}_c)$	0.06	0.09
Total share of energy expenditures	$\bar{E}^r / (\bar{E}^r + \bar{C})$	0.102	0.102
Interest rate annualized	$\bar{R}$	1.034	1.03

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